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MICROSTRUCTURE, MECHANICAL PROPERTIES AND DAMPING CAPACITY OF A SONOSTON PROPELLER BLADE

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METALLURGY and METAL PHYSICS SECTIONS

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ABSTRACT

Examination of two Sonoston propeller blades, received from Defence Research Establishment Atlantic (DREA), Halifax, showed that the propeller possessed relatively high damping capacity despite several years storage in the dock yard at ambient temperatures. The ultimate tensile strength (UTS), % elongation and Charpy V-notch (CVN) impact toughness values of the blade are low in comparison with separately cast bars. The low impact toughness of 8 J and evidence from an examination of the fracture surfaces indicate that the propeller is likely to fail in a brittle manner on impact loading.

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MICROSTRUCTURE, PROPRIÉTÉS MÉCANIQUES ET CAPACITÉ D'AMORTISSEMENT DES PALES D'HÉLICE EN SONOSTON

par

M. Sahoo, V.E. Moore et G. Weatherall

RÉSUMÉ

L'examen de deux pales d'hélice en Sonoston provenant du Centre de recherche pour la défence/Atlantique (CRDA), Halifax, a démontré que l'hélice possédait une capacité d'amortissement relativement élévée bien qu'ayant été entreposée à la température ambiante sur des chantiers de construction navale durant plusieurs années. Les valeurs de la charge limite de rupture (UTS), du pourcentage d'allongement et de la résilience Charpy (CVN) des pales sont faibles comparativement à celles de barreaux d'essai moulés individuellement. La faible résilience de 8 J et les résultats d'un examen des plans de fracture indiquent que l'hélice devrait vraisemblablement être sujette à la rupture fragile sous charge de choc.

INTRODUCTION

PMRL/CANMET is engaged in a research program, on behalf of the Canadian Armed Forces (Navy), to evaluate the foundry characteristics, mechanical properties and damping capacity of the high-damping propeller alloy Sonoston. As part of this research program, it was of interest to examine the microstructure, and to determine the mechanical properties and damping capacity of a propeller blade. To this end, the Defence Research Establishment Atlantic (DREA) supplied two propeller blades cut from a four-blade integral-cast propeller.

DESCRIPTION OF THE PROPELLER BLADE

Photographs of one of the propeller blades are shown in Figs. 1(a) and (b) to reveal its shape. The length of each blade was about 115 cm. The widths at the thick end (cut from the boss) and mid-section were respectively 44 and 45 cm. The maximum thickness at the thick-end was about 12 cm. Each blade weighed about 180 kg.

Samples were removed from the thick-end, mid-section and propeller tip (see Fig. 2) to machine 13 mm diam tensile specimens, Charpy V-notch (CVN) impact specimens and damping specimens. The damping studies were done at the Whiteshell Nuclear Research Establishment, Pinawa, Manitoba on strip specimens of 50 x 2.5 x 1.3 mm.

COMPOSITION

The compositions of the blade, determined at two positions by wet chemical analysis, are shown in Table 1 together with the nominal compositions suggested by the manufacturers. It is evident that the compositions at the thick and thin ends of the blade are similar and meet the specifications of the manufacturer.

MICROSTRUCTURES

Optical micrographs of the as-received propeller are shown in Figs. 3(a) and (b) for the thick and thin ends respectively. These cored microstructures are similar to those observed in as-cast keel blocks (1). However, the thick-end of the propeller shows a relatively coarse microstructure because of slow cooling. The interdendritic spacing in the thin-end of the

propeller almost matches that of separately-cast keel block test bars. There is also a relatively large volume fraction of Cu_3Mn_2Al precipitates in the interdendritic regions of the as-received propeller.

Electron microprobe analysis was performed on the two sections. Concentration profiles characteristic of dentritic structures are shown in Figs. 4 and 5 for the thick and thin sections respectively. It is evident that aluminum and nickel are uniformly distributed throughout the matrix except in the interdendritic precipitates which show a relatively high concentration of Al and Ni. There is definite periodicity in the solute distribution curves for Mn, Cu and Fe. In each case, dendrite arms are rich in Mn and Fe and depleted in Cu. Although interdendritic regions have a high concentration of Cu, Mn is still the major constituent. Because segregation is affected by the cooling conditions in the propeller, the absolute concentrations of Mn, Cu and Fe vary from the thick section to the thin section. However, as shown in Table 2, the segregation ratio for each solute is similar for the two extreme cooling conditions except for Cu. In Figs. 4 and 5, the unusually high Al and Ni contents in the interdendritic regions correspond to Cu_3Mn_2Al precipitates.

MECHANICAL PROPERTIES

Mechanical properties of the blade determined at three positions are summarized in Table 3 together with the properties specified by the manufacturer for Sonoston. For comparison, mechanical properties of a separately cast bar of similar composition (from Ref. 1) are included in the same Table. Results show that the mechanical properties, especially UTS and % elongation are very sensitive to section thickness and hence, cooling rate during solidification. These properties are lowest in the thick section where the cooling rate is slowest. In general, the UTS, % elongation and CVN impact toughness are lower in the propeller blade compared with separately-cast test-bar properties and the manufacturer's suggested values. The impact toughness, in particular, is reduced by more than 70% and the very low value of 8 J indicates the material is susceptible to brittle failure from impact loading. Examination of the impact fracture surface under the scanning electron microscope showed cleavage fracture and a lot of microcracks (Fig. 6).

The effect of test temperature on CVN impact toughness of the as-received blades is shown in Fig. 7. It is evident that there is no sharp

transition in the impact energy-temperature plot. The impact toughness of the thin end of the propeller is slightly higher than that of the thick end at sub-zero temperatures.

DAMPING CAPACITY

Preliminary results on specific damping capacity (SDC) are given in Table 4 for specimens removed from various locations of the propeller. The average damping capacity of the propeller is 5.9%. However, the thin-end of the propeller appears to have higher specific damping capacity than the thick-end. It should be noted that Sonoston specimens prepared in the PMRL foundry had a specific damping capacity of only 1% for specimens stored at ambient temperatures for several months in both the as-cast and aged condition (1). It is interesting to note that a Sonoston propeller stored in a Halifax dockyard for several years has a significantly higher damping capacity.

DISCUSSION

The mechanical properties of the Sonoston propeller blade are similar to these reported by Langham (2). He showed that the mechanical properties of 2000 kg cast propellers can vary from blade tip (532/295/17.5)* to blade root (465/303/14.5) and boss (455/293/13), and are less than those obtained from separately-cast test bars (586/288/37). Langham did not report the impact toughness of his cast propeller. The results of the present investigation show that the impact toughness of a cast propeller is reduced dramatically by slow cooling. This is a similar observation to those made in the case of Ni-Al and Mn-Ni-Al bronze propellers (3).

The low impact toughness (10 J) at the propeller tip is surprising. However, cooling curves for Mn-Ni-Al bronze propellers (4) show that although the thin end (blade tip) of the propeller cools more quickly (than the heavy section) in the first few hours after the molten metal is poured, the rate of cooling decreases as heat flows "back" from the thick section of the blade. This evidence is consistant with the notion that impact toughness is reduced by a phrase transformation that occurs because of slow cooling at temperatures below about 600°C. Becuase α-Mn is precipitated when Sonoston is aged at

*UTS/0.15% proof stress/% elongation.

temperatures up to 600°C (1), it is possible that the precipitation of α-Mn induced by slow cooling reduces the impact toughness.

Transmission electron microscopy will be done to correlate microstructure with mechanical properties and damping capacity as well as to explain the reason for the higher damping capacity of the Sonoston propeller blade compared with the very low damping capacity of the alloy prepared at PMRL.

CONCLUSIONS

1. The average mechanical properties of the Sonoston propeller blade are 472 MPa UTS, 308 MPa 0.2% yield strength, 9% elongation and 8 J CVN impact toughness.
2. The UTS, % elongation and impact energy values are low in comparison with separately cast test bars.
3. Coring is present in the structure. The interdendritic spacing of the thin end is finer than that of the thick end.
4. The propeller has a relatively high damping capacity despite several years storage at ambient temperatures in the Halifax Dockyard.

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2. Langham, J.M. "A new high damping alloy"; Foundry Trade Journal, vol 124, p 989-998 (June 6, 1968).

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Table 1. Chemical analysis (wt %) of the propeller blade.

Location	Mn	Cu	Al	Ni	Fe	Si	C
Thick end (DR 3)	Bal	38.4	4.35	1.44	3.20	0.07	0.094
Thin end (DR 6)	Bal	38.3	4.36	1.42	3.16	0.07	0.095
Nominal composition*	54.25	37.0	4.25	1.5	3.0	-	-

*Specified by the manufacturer.

Table 2. Typical distribution of solute concentrations across dendrites.

Elements	Thick-end			Thin-end		
	C_c*	C_i**	Segregation ratio, C_i/C_c	C_c*	C_i**	Segregation ratio, C_i/C_c
Mn	63.96	46.77	0.73	75.15	54.54	0.73
Cu	25.95	46.11	1.78	12.93	38.62	2.99
Fe	5.01	1.27	0.25	9.38	2.29	0.24
Al	3.84	4.18	1.09	4.20	3.57	0.85
Ni	1.29	1.45	1.12	0.97	1.29	1.33
Si	0.088	0.053	0.60	0.081	0.086	1.06

* C_c = solute concentration, wt % in dendrites.

** C_i = solute concentration, wt % in inter-dendritic regions.

Table 3. Mechanical and physical properties of Sonoston propeller blade and other cast materials.

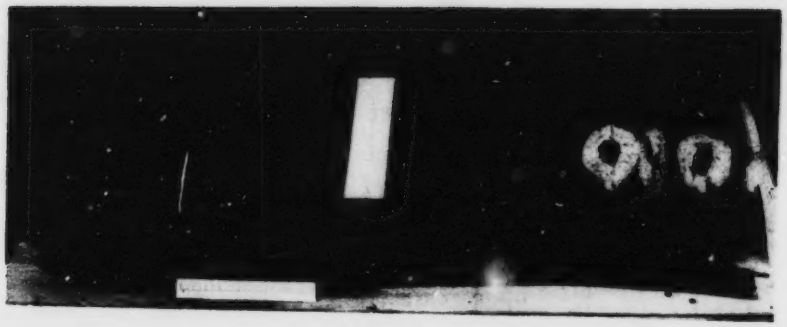
Specimen No.	UTS MPa	0.2% offset YS MPa	0.5% YS MPa	Elong. % in. 4 D	Density g/cm^3	Hardness HRB	CVN impact energy, J	
							RT	-50°C
DR 3	444	303	296	6	7.198	81	7	6
DR 7	501	313	296	11	7.178	80	8	6
DR 6	-	-	-	-	7.150	82	10	9
2468 (keel block)	550	269	263	40	7.162	76	46	41
Manufacturer's suggested values	540-590	250-* 280	-	13-30	7.1	80	25-** 55	

* 0.1% proof stress.

**Izod impact value.

Table 4. Specific damping capacity of Sonoston propeller blade.

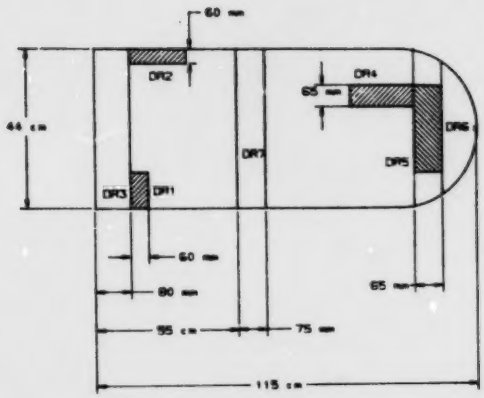
Sample No.	Test temp °C	Surface stress amplitude MPa	Specific damping capacity %
DR 1	15	12.0	5.5
DR 2	14	11.7	5.12
DR 4	12	12.4	6.82
DR 5	12	13.1	6.26



(neg 9308)

(neg 9310)

Fig. 1. Photographs of one of the propeller blades.

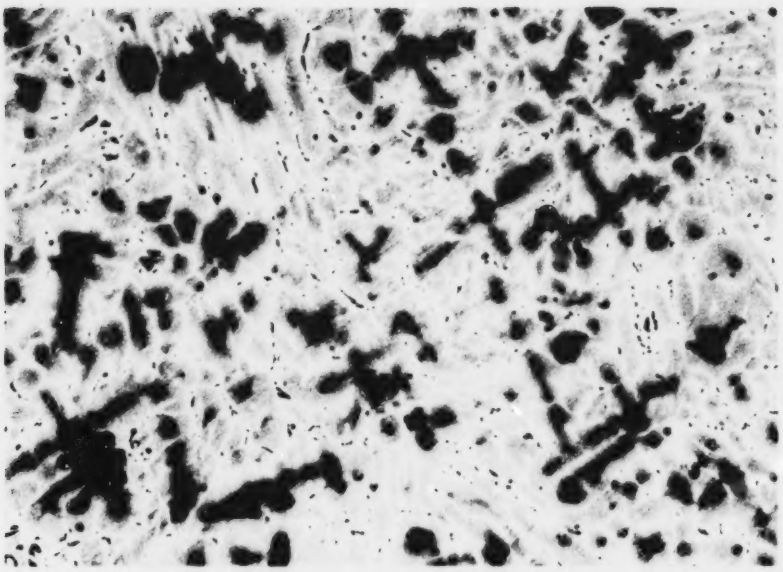


DR 1
DR 2
DR 4
DR 5
} DAMPING STUDIES

DR 3
DR 7
} TENSILE AND IMPACT STUDIES

DR 6 IMPACT STUDIES

Fig. 2. Schematic representation of propeller blade to show locations of tensile impact and damping specimens. (neg 11715)



(a) thin-end (propeller tip) (neg 11562)

(b) thick-end (near propeller hub) (neg 11563)

Fig. 3. Optical micrographs of the as-received sonoston propeller. Alcoholic ferric chloride etch. X200.

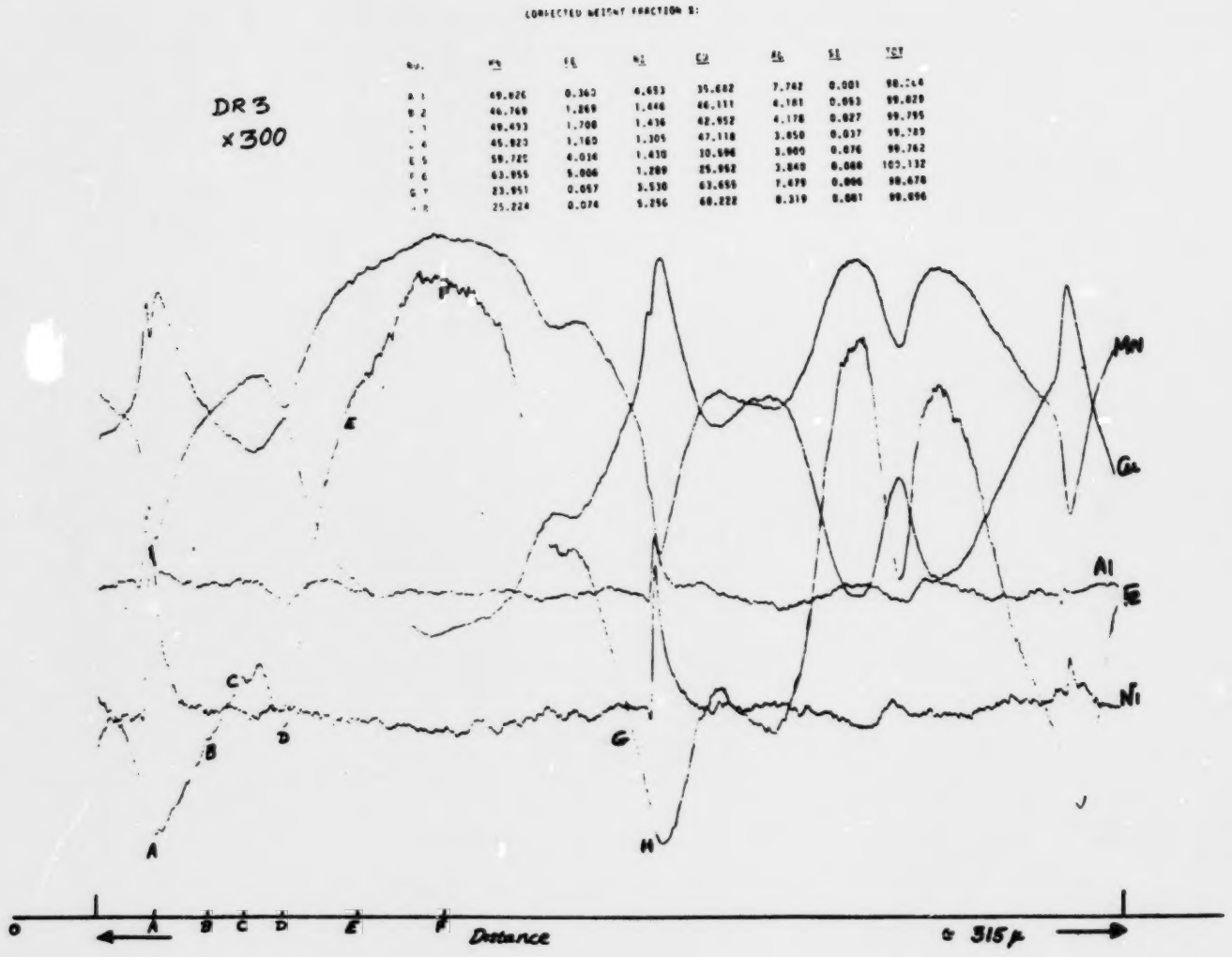


Fig. 4. Electron microprobe analysis characterizing solute distribution across dendritic and interdendritic regions in the thin-end of the propeller blade. (neg 11557)

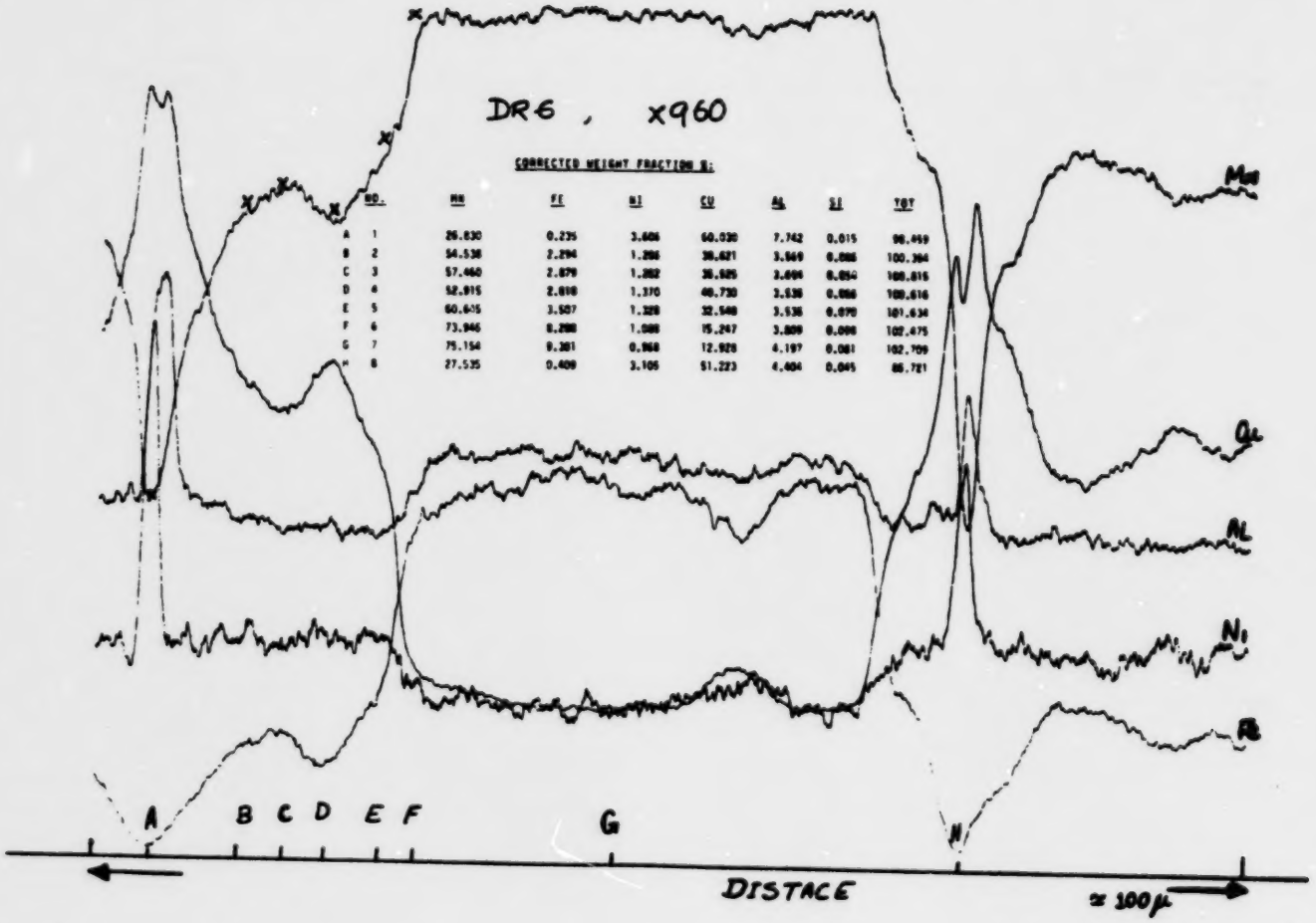
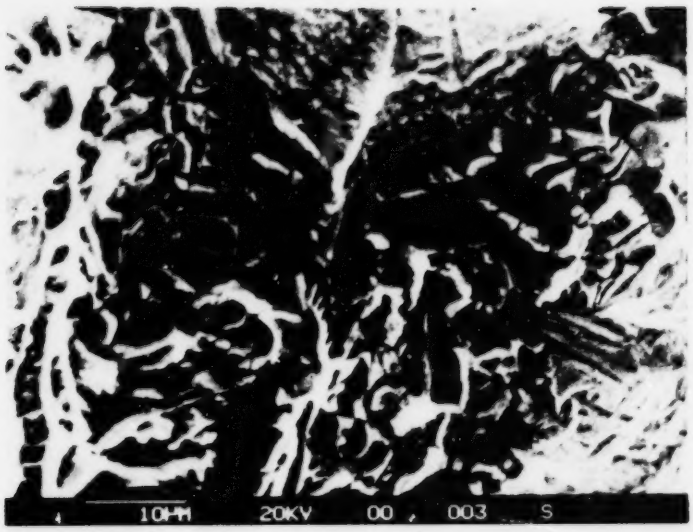
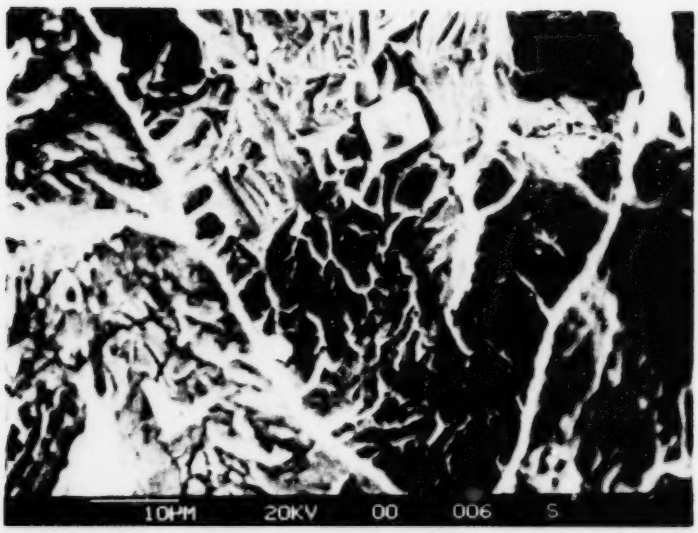


Fig. 5. Electron microprobe analysis characterizing solute distribution across dendritic and interdentritic regions in the thin-end of the propeller blade. (neg 11556)



(neg 11560)



(neg 11561)

Fig. 6. Scanning electron micrograph of the fracture surface of the thick end of the sonoston propeller blade. Room temperature CVN impact toughness of only 7J.

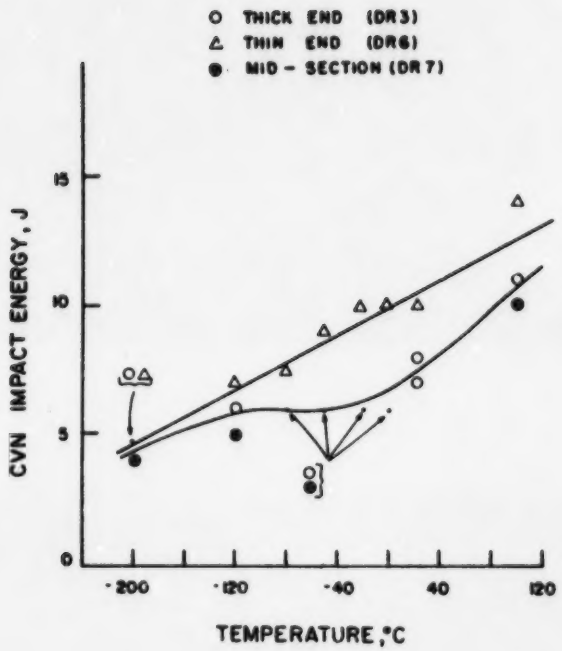


Fig. 7. CVN impact energies as a function of test temperature for sonoston propeller blade. (neg 11716)